

The Mass of the Centaurus A Group of Galaxies

Sidney van den Bergh
 Dominion Astrophysical Observatory
 National Research Council
 5071 West Saanich Road
 Victoria, British Columbia, V8X 4M6
 Canada
 vdb@dao.nrc.ca

ABSTRACT

The mass M , and the radius R_h , of the Centaurus A group are estimated from the positions and radial velocities of 30 probable cluster members. For an assumed distance of 3.9 Mpc it is found that $R_h \sim 640$ kpc. The velocity dispersion in the Cen A group is 114 ± 21 km s $^{-1}$. From this value, and $R_h = 640$ kpc, the virial theorem yields a total mass of $1.4 \times 10^{13} M_\odot$ for the Cen A group. The projected mass method gives a mass of $1.8 \times 10^{13} M_\odot$. These values suggest that the Cen A group is about seven times as massive as the Local Group. The Cen A mass-to-light ratio is found to be $M/L_B = 155 - 200$ in solar units. The cluster has a zero-velocity radius $R_0 = 2.3$ Mpc.

Subject headings: Galaxies: clusters: individual (Centaurus A)

1. Introduction

The loose clustering of galaxies surrounding Centaurus A was called the NGC 5128 Group by de Vaucouleurs (1975), who designated it G4 because it was the fourth closest group of galaxies in his compilation. This group is primarily of interest because its brightest member is the galaxy NGC 5128, which contains the radio source Centaurus A. This object is also [with the exception of Maffei 1 (van den Bergh 1971, Huchtmeier, Karachentsev & Karachentsev 1999)] the nearest early-type giant galaxy. De Vaucouleurs recognized the galaxies NGC 4945, 5068, 5102, 5128, 5236 and 5253 as probable group members. Using more recent data Hesser et al. (1984) assigned 20 galaxies to this group. From their data these authors derived a group mass of $8 - 25 \times (D/5\text{Mpc}) \times 10^{12} M_\odot$. Using Hubble Space Telescope (HST) observations of the tip of the red giant branch in NGC

5128 Harris, Poole & Harris (1998) obtained a distance modulus $(m-M)_0 = 27.89 \pm 0.15$, corresponding to a distance of 3.9 ± 0.3 Mpc. This value is in good agreement with $(m-M)_0 = 27.8 \pm 0.2$ (3.6 ± 0.2 Mpc) that Soria et al. (1996) had previously found using the same method. Independent distance estimates are by Hui et al. (1993) who, after correction to modern Local Group distances, found $(m-M)_0 = 27.97 \pm 0.14$ from the luminosity function of planetary nebulae, and by Tonry & Schechter (1990) who obtained $(m-M)_0 = 27.53 \pm 0.25$, corresponding to 3.2 ± 0.4 Mpc, from surface brightness fluctuations in NGC 5128.

It would be of interest to search for Cepheids among the young blue stellar populations (van den Bergh 1976a) that are associated with the dark band of gas and dust which crosses the face of NGC 5128. It is generally believed that the present, rather chaotic, morphology of NGC 5128 is due to the fact that this object recently merged with a spiral galaxy. The S0pec galaxy NGC 5102 in the Cen A group is presently undergoing a burst of star formation, which may have been triggered by gas captured from the luminous Sc spiral NGC 5253 about 4×10^8 years ago (van den Bergh 1976b).

An independent check on the distance of the Centaurus A group is provided by HST observations of Cepheids in NGC 5253 (Saha et al. 1995), which yields $(m-M)_0 \sim 28.1$, corresponding to $D = 4.2$ Mpc. In the subsequent discussion a distance of 3.9 Mpc will be adopted for both NGC 5128 and for the Cen A cluster. From a historical point of view it is of interest to note that this value is, within its errors, indistinguishable from the distance $D = 4.0$ Mpc adopted by de Vaucouleurs (1975). This serves to illustrate the fact that the extragalactic distance scale, out to distances of ~ 10 Mpc, has remained essentially unchanged for a quarter of a century.

2. Cluster Distance and Radius

A catalog of possible members of the Centaurus group has been published by Côté et al. (1997). More recently Banks et al. (1999) have obtained HI observations for a number of cluster suspects. Table 1 gives data on 30 probable group members. Following Banks et al. the galaxy CEN 5, which has a heliocentric radial velocity of only $+130 \text{ km s}^{-1}$, has been omitted as a probable foreground object. Alternatively it might be a background galaxy that is superposed on a local high-velocity cloud. Also omitted is NGC 5068, which lies 22° north of the main concentration of Centaurus A group members. Data listed in the table are: (1) Galaxy name, (2) alias, (3) angular distance from NGC 5128, (4) radial velocity corrected to the centroid of the Local Group, assuming a solar velocity of 306 km s^{-1} towards $\ell = 99^\circ$, $b = -4^\circ$ (Courteau & van den Bergh 1999), and (5) the galactic HI

content in units of $10^6 M_\odot$ from Banks et al. (1999).

The data plotted by Banks et al. show that the Centaurus group has a rather irregular structure. Nevertheless, it will be assumed that this group is dynamically centered on NGC 5128, which is its most luminous (and presumably most massive) member. The distribution of the angular distances of individual galaxies in the Centaurus group from NGC 5128 is shown in Figure 1. Taken at face value the data plotted in the figure suggest that half of the members of the Centaurus group are situated within $\sim 9.^\circ 5$ of NGC 5128. At a distance of 3.9 Mpc this yields $R_h = 640$ kpc. The true half-mass radius is expected to be smaller than this value because a significant fraction of the cluster mass is associated with the central galaxy NGC 5128. On the other hand the incompleteness of the sample at $R(\text{NGC 5128}) > 14^\circ$ will lead to an underestimate of the true half-mass radius. It is noted in passing that the value $R_h \sim 640$ kpc for the Cen A group is larger than the value $R_h \sim 350$ kpc, which Courteau & van den Bergh (1999) find for the Local Group. Furthermore the ~ 900 kpc projected separation, between the dominant galaxies NGC 5128 and NGC 5253, is slightly larger than the 760 kpc linear separation (van den Bergh 2000) of the Milky Way system and the Andromeda galaxy.

3. Mass of the Centaurus A Cluster

If it is assumed that the Cen A cluster is in virial equilibrium, and that its velocity ellipsoid is isotropic ($\sigma^2 = 3\sigma_r^2$), then its mass can be computed from its velocity dispersion and half-mass radius (Spitzer 1969). According to Binney & Tremaine (1987, Eq. 4-80b)

$$M_v \simeq \frac{7.5}{G} \langle \sigma_r^2 \rangle r_h = 1.74 \times 10^6 \langle \sigma_r^2 \rangle r_h M_\odot, \quad (1)$$

in which σ_r is in km s^{-1} and r_h is in kpc. From the data in Table 1 the radial velocity dispersion $\sigma_r = 114 \pm 21 \text{ km s}^{-1}$. Substituting this value into Eqn. (1) yields a total cluster mass of $1.4 \times 10^{13} M_\odot$. For comparison it is noted that Courteau & van den Bergh (1999) found a mass of only $2.3 \times 10^{12} M_\odot$ for the Local Group. Reasons for this difference are that (1) the radial velocity dispersion in the Local Group is only $\sigma_r = 61 \text{ km s}^{-1}$, and (2) the adopted half-mass radius of Cen A is $R_h = 0.64 \text{ Mpc}$, compared to $R_h \simeq 0.35 \text{ Mpc}$ for the Local Group.

Alternatively the mass of the Centaurus A group may be estimated using the projected mass method of Bahcall & Tremaine (1981). According to Heisler, Tremaine, & Bahcall (1985) the projected mass estimator may be expressed as

$$M_p = \frac{10.2}{G(N - 1.5)} \sum_i V_{r,i}^2 R_i, \quad (2)$$

in which N is the number of cluster galaxies and G is the gravitational constant. From the data in Table 1 this yields $M_p = 1.8 \times 10^{13} M_\odot$, which is in reasonable agreement with the virial mass of $M_v = 1.4 \times 10^{13} M_\odot$. The $14 - 18 \times 10^{12} M_\odot$ mass of the Cen A group is about seven times greater than the $(2.3 \pm 0.6) \times 10^{12} M_\odot$ mass that Courteau & van den Bergh (1999) derived for the Local Group.

The mean velocity of the Cen A group, relative to the centroid of the Local Group, is $+278 \pm 21 \text{ km s}^{-1}$. This value is, within its errors, indistinguishable from the $+295 \text{ km s}^{-1}$ velocity of NGC 5128 relative to the Local Group. The cluster velocity of $+278 \text{ km s}^{-1}$, in conjunction with a distance of 3.9 Mpc, yields a Hubble parameter $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$. The fact that this value is so close to the numerical value of H_0 , that is derived from observations of distant galaxies, suggests that the local region of the Universe may be rather cold.

The radius of the zero-velocity surface, which separates the cluster from the Hubble flow (Lynden-Bell 1981, Sandage 1986), is given by

$$R_0[\text{Mpc}] = \left(\frac{8GT^2}{\pi^2} M \right)^{1/3} = 0.154(T[\text{Gyr}])^{2/3}(M[10^{12}M_\odot])^{1/3}. \quad (3)$$

Assuming $M = 16 \times 10^{12} M_\odot$ and $T = 14 \text{ Gyr}$ one obtains $R_0 = 2.3 \text{ Mpc}$, corresponding to an angular size of 35° . The radius of the zero-velocity surface of the Local Group is 1.2 Mpc (Courteau & van den Bergh 1999). The distance to the Cen A group is 3.9 Mpc, and the radii of the zero-velocity surfaces of the Cen A group and Local Group are 2.3 Mpc and 1.2 Mpc, respectively. The zero velocity surfaces of these two clusters therefore almost touch each other. This suggests that the early evolution of the Local Group may have been dynamically affected by the Cen A group.

4. Luminosity of the Centaurus A Group

De Vaucouleurs et al. (1991) list luminosities and absorption values for 16 of the brightest galaxies in Table 1. For an assumed distance of 3.9 Mpc these objects have a combined absolute magnitude $M_B = -21.9$. Of this luminosity 58% is contributed by NGC 5128 itself. The three brightest cluster galaxies (NGC 945, NGC 5128 and NGC 5256) together provide 89% of the total group luminosity calculated above. These data suggest that the fainter group galaxies provide only a negligible contribution to the total group luminosity. Adopting $M_B = -21.9$ and $M_B(\odot) = +5.48$ yields a total cluster luminosity $L_B = 9 \times 10^{10} L_B(\odot)$. In conjunction with a total cluster mass of $14 - 18 \times 10^{12} M_\odot$, this

yields $M/L_B = 155 - 200$ in solar units. With $h = (H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}) \sim 0.7$ this is quite similar to the value $M/L_B \sim 250 h$ (in solar units) that Girardi et al. (1999) obtain for poor nearby Abel clusters. However, it is larger than the value $M/L_V = 44 \pm 12$ that Courteau & van den Bergh (1999) find for the Local Group.

5. Conclusions

The Centaurus A group is an irregular clustering centered on NGC 5128. This group has a mass which is about seven times greater than that of the Local Group. It is located at a distance of ~ 3.9 Mpc, and is found to have a mass-to-light ratio (in solar units) of 155–200, which is quite similar to the mass-to-light ratios found for typical poor Abel clusters. The Cen A group has a half-light radius of ~ 640 kpc. Its zero-velocity surface (assumed to be spherical) has a radius $R_0 = 2.3$ Mpc. Since this value is more than half of the distance to NGC 5128, it appears probable that the Cen A cluster may have had a significant influence on the early dynamical evolution of the Local Group.

I am indebted to Stéphanie Côté for reading, and commenting on, an earlier version of this paper.

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Table 1. DATA ON CENTAURUS A CLUSTER

(1) Galaxy	(2) Alias	(3) D(5128)	(4) V_{LG} (km s ⁻¹)	(5) ^a M_{HI}
ESO 321-G014	UKS 1243-336	14.°36	+333	19
ESO 381-G018		10.61	+349	13
ESO 381-G020		11.98	+333	100
Cen 8		4.79	+350	20
NGC 4945		7.39	+299	990
ESO 269-G058		4.77	+133	21
1321-31		11.51	+355	24
NGC 5102		6.42	+225	320
AM 1321-304		12.05	+268	11
NGC 5128		0.00	+295	490
IC 4247	Cen A	12.65	+191	18
ESO 324-G024		1.58	+268	120
1328-30		12.59	-28	32
NGC 5206		5.33	+312	...
ESO 270-G017		3.03	+575	740
NGC 5236		13.31	+288	3700
1337-39		3.86	+246	23
NGC 5237		2.24	+111	33
NGC 5253		11.72	+175	150
NGC 5264		13.50	+281	82
ESO 272-G025	UKS 1342-416	14.12	+402	...
ESO 325-G011		3.79	+306	77
ESO 174-G001		10.98	+422	210
1348-37		6.71	+336	12
ESO 383-G087		8.35	+100	90
1351-47		6.02	+281	13
NGC 5408		7.20	+267	160
UKS 1424-460		11.59	+150	61
ESO 222-G010		13.58	+388	26
ESO 274-G001		19.53	+314	430

^aThese masses by Banks et al. (1999) are based on an assumed distance of 3.5 Mpc and should be multiplied by a factor of 1.24 if the true cluster distance is 3.9 Mpc.

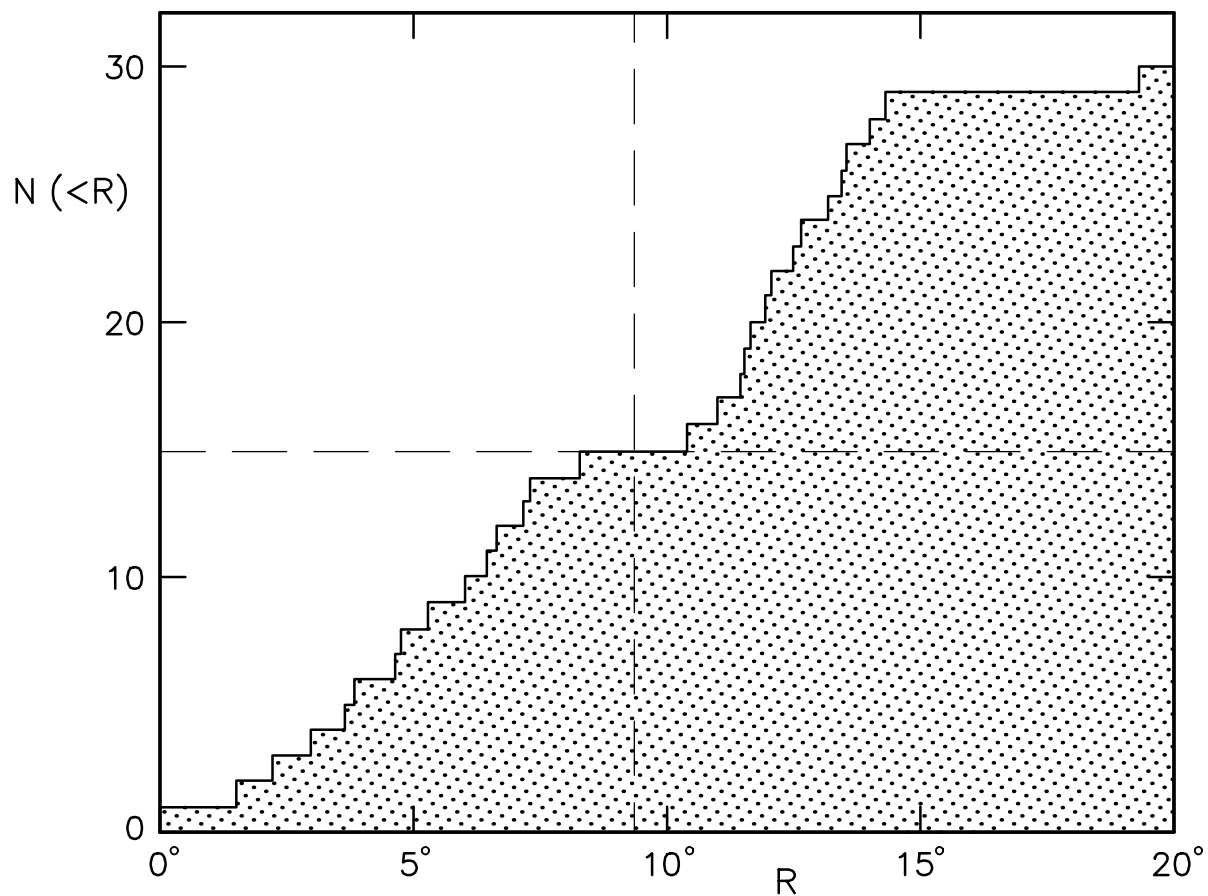


Fig. 1.— Integral distribution of galaxy distances from NGC 5128. Half of the known cluster members are located within ~ 9.5 degrees of this galaxy. The mass distribution in the Cen A group may be more centrally concentrated than that of the galaxies. The data are incomplete for $R > 14^\circ$.